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DESCRIPTION

RFID TAG DEVICE

TECHNICAL FIELD

[0001]The present invention relates to RFID tag devices, and specifically to an RFID tag device based on passive modulation, but capable of performing, for example, QPSK modulation for wireless communication by using a loop antenna or a dipole antenna.

BACKGROUND ART

[0002] Patent Document 1: Japanese Laid-Open Patent Publication No. 10-224262

[0003] (Tags for radio frequency identification communication systems)

RFID is wireless equipment for identifying mobile objects, which is attached to or held by a commodity, a person, a car, a road sign, etc., and in response to a radio wave from an interrogator (a reader/writer), notifies individual information and position information to the interrogator.

[0004] The RFID is considered not only as an alternative to the barcode, but also as elemental technology for implementing an entirely new infrastructure for a future network community. The research and development of RFID currently underway mainly concentrates on communication

within a relatively short range of several tens of centimeters, but if it is possible to realize low-cost small RFID tags capable of communication from relatively afar, such as from about 10 meters away, the application range will be conceivably further extended.

[0005] When such is attached to a commodity, a person, a car or a road sign, for example, its individual information and position information are read by a mobile object from 10 m away, making it possible to readily enjoy safety and convenience.

[0006] The above Patent Document 1 describes a conventional passive RFID tag device. According to this, the conventional passive RFID tag device is basically configured as shown in FIG. 1, and therefore has a problem that its possible communication range is short for the following reasons.

(1) A response signal is created by regularly changing impedance Z_v between an antenna feeding point and GND to repeat reflection and absorption of incident radio waves, so that the transmission output (conversion efficiency) is low, and the load impedance Z_v is applied between the feeding point and GND, resulting in considerable loss of received power.

(2) The source voltage for a control circuit is created by directly diode-rectifying an RF signal received at the antenna feeding point, and therefore the output voltage is low.

(3) ASK or BPSK is used as a subcarrier modulation scheme, and therefore the amount of information that can be transmitted per transmission power is small.

DISCLOSURE OF INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0007] The present invention aims to overcome the drawback with the above conventional technology by the configuration shown in FIG. 2, and expand the communication range to several times or more that in the conventional scheme.

MEANS FOR SOLVING PROBLEM

[0008] The main points of the present invention for solving the above problems are as shown below.

[0009] The conventional scheme is based on equilibrium feeding/equilibrium modulation (a two-terminal circuit for antenna operation), whereas a method of the present invention is based on disequilibrium feeding/equilibrium modulation (a three-terminal circuit for antenna operation). The conventional scheme is based on simple rectification of received RF signals, whereas the present invention employs a circuit based on a combination of a stub resonance-based, impedance transformation boosting scheme and a ladder boosting scheme. The conventional scheme is based on ASK or BPSK modulation, whereas the present invention is based on

passive modulation, but can employ a QPSK modulation circuit.

[0010] Specifically, an RFID tag device of the present invention includes a divided microstrip antenna, a power receiving circuit based on a combination of a stub resonance-based, impedance transformation RF boosting scheme and a ladder boosting/rectifying scheme, and a local oscillator circuit for generating a response subcarrier signal, and a dividing position of the divided microstrip antenna is slightly deviated from a longitudinal center point across strip conductors. In the present invention, a passive QPSK modulation scheme is usable as a modulation method.

[0011] Also, according to the RFID tag device of the present invention, it is preferred that impedance modulation elements of the divided microstrip antenna are respectively connected to opposite ends in a strip conductor width direction so as to connect divided conductors.

The impedance modulation elements are preferably PIN diodes or varactor diodes. Also, a voltage or current controlled three-terminal element using a transistor, rather than a diode, is preferable.

[0012] Further, according to the RFID tag device of the present invention, an extremely small capacitance (1 pF/GHz or less) is preferably used for connecting the power receiving circuit and an antenna feeding point to

perform high-impedance capacitive feeding. Note that in order to maximize the receiving efficiency of the antenna, the antenna feeding point may be positioned so as not to correspond to a dividing point of the divided microstrip antenna.

[0013] Also, according to the RFID tag device of the present invention, it is preferred that capacitive load impedances in a stub resonator and a ladder boost rectifier circuit of the power receiving circuit are parallel resonant, and further, the capacitive feeding impedance are series resonant.

[0014] Further, according to the RFID tag device of the present invention, it is preferred that when considering longitudinal connections of capacitors in the ladder boost rectifier circuit of the power receiving circuit as GND- and receiving-side rails, capacitor capacitance of the receiving-side rail is smaller than that of the GND-side rail, a first diode between GND and a receiving point is eliminated, and a high-frequency and high-impedance input is receivable by a DC short.

[0015] Also, according to the RFID tag device of the present invention, a logic circuit including a 1/4 frequency divider, a shift register and a data selector is preferably used in the passive QPSK modulation method, and MPSK modulation is preferably applied by using a 1/M frequency divider, an M-stage shift register and an M-input data selector.

[0016] Further, according to the RFID tag device of the present invention, information is preferably recorded to a memory in units of two bits in accordance with the passive QPSK modulation method.

[0017] Also, the RFID tag device of the present invention preferably includes an timing generator circuit for obtaining an output enable signal in the passive QPSK modulation method, and the output timing generator circuit preferably generates a train of pulses with a random delay time having a fixed width and a fixed frame cycle, based on a source voltage size and a clock signal.

[0018] According to the RFID tag device of the present invention, it is preferred that by using a transducer such as a temperature sensor quartz resonator as the local oscillator circuit for generating the response subcarrier signal, a sensor function capable of allowing its oscillating frequency to be read by an external unit is additionally used.

According to a position detecting method for a mobile object having no RFID tag of the present invention, in a system composed of the RFID device and one or more master devices (interrogators), whether or not an obstacle is present in a radio wave propagation path extending between each RFID tag device and each interrogator is determined based on the presence or absence of communication between the RFID tag and the

interrogator.

[0019] In the position detecting method for a mobile object having no RFID tag, a plurality of radio wave propagation paths present between each RFID tag and each interrogator are preferably distinguished based on a combination of a local oscillating frequency for generating a response subcarrier of each RFID tag, a response timing and a frequency of an interrogation radio wave outputted from the interrogator and timing of generating the interrogation radio wave.

According to a position detecting method for a mobile object having an RFID tag of the present invention, radio waves at two or more frequencies are transmitted to an RFID tag device from an interrogator having two or more antennas dedicated for reception or used for transmission and reception, and based on a difference in phase (a difference in delay time) between receiving antennas in a signal for response thereto, maximum likelihood determination of a position of the RFID tag is performed.

[0020] According to the position detecting method for a mobile object having an RFID tag, in the case where in order to enable a three-dimensional RFID tag position determination, an interrogation device having four or more antennas dedicated for reception or used for transmission and reception is used, it is preferred to eliminate a commonly measured distance offset by

obtaining a group delay time in each radio wave propagation path based on four or more sets of frequency responses measured for the two or more frequencies, and obtaining a difference in delay time with reference to at least one of the sets.

It is preferred that the RFID tag device of the present invention includes two or more tag antennas in order to expand its possible communication range.

[0021] According to a communication method of the present invention, the RFID tag device periodically changes directionality of an intense response subcarrier radio wave, which is synthesized by periodically changing a phase of a local oscillating signal provided to each tag antenna for generating a response subcarrier signal, thereby returning an intense response radio wave toward an interrogator in a wide area.

EFFECT OF THE INVENTION

[0022] By employing these configurations, it is made possible to achieve considerable effects as below.

[0023] Disequilibrium feeding and equilibrium modulation (a three-terminal circuit for antenna operation) are employed, and therefore it is possible to achieve the effect of maximizing the reception efficiency of an antenna.

[0024] Also, by employing a circuit based on a combination of a stub resonance-based, impedance

transformation boosting scheme and a ladder boosting scheme, it is possible to obtain a reception voltage of five times or more that of conventional schemes.

[0025] Further, by employing a QPSK modulation circuit, but based on passive modulation, it is made possible to transmit information in an amount twice that of the conventional method per unit of transmitting power.

BRIEF DESCRIPTION OF DRAWINGS

[0026] FIG. 1 is a schematic diagram illustrating a conventional RFID tag device;

FIG. 2 is a schematic diagram illustrating an RFID tag device of the present invention;

FIG. 3 is a perspective view illustrating Example 1 of the present invention;

FIG. 4 is a top view illustrating a control circuit chip of the present invention;

FIG. 5 is a diagram illustrating an example of an impedance modulation element of the present invention;

FIG. 6 is a diagram illustrating Example 2 of the present invention;

FIG. 7 is a diagram illustrating Example 3 of the present invention;

FIG. 8 is a diagram illustrating Example 4 of the present invention;

FIG. 9 is a diagram illustrating Example 4 of the present invention;

FIG. 10 is a graph showing frequency response characteristics of a 10-stage Cockcroft-Walton circuit (-3 dBm input, HRU0302A, C_o = 70 pF);

FIG. 11 is a graph showing frequency response characteristics of a 10-stage Cockcroft-Walton circuit (-3 dBm input, HSB226, C_o = 2.4 pF);

FIG. 12 is a diagram showing a batch reading (Anticollision) method for a plurality of RFIDs;

FIG. 13 is a graph showing a batch reading simulation for a plurality of RFIDs, "packet transmission at a random time within a 1-second frame", packet duration / simultaneously readable number.

FIG. 14 is a diagram illustrating a planar antenna structure for RFID and a simulation model.

FIG. 15 is a graph showing an RFID response receiver frequency spectrum (obtained by HP83620A, Synthesized Sweeper);

FIG. 16 is a comparison graph of receiver gain for modulated waves from RFID (transmission/reception $\lambda/2$ dipole, distance $z = 5\lambda$);

FIG. 17 a graph showing frequency response characteristics of a stub resonance boost rectifier circuit (-10 dBm input, RL = 33 kΩ by SPICE simulation);

FIG. 18 is a graph for a comparison of RFID response receiver sensitivity frequency characteristics by changing a height between a microstrip line and GND

(distance $z = 5\lambda$, $w = 0.0525\lambda$, $R = 0\Omega$, $C_o = 1$ pF);

FIG. 19 is a graph for a comparison of RFID response receiver sensitivity frequency characteristics by changing the width of a microstrip line (distance $z = 5\lambda$, $h = 0.021\lambda$, $R = 0\Omega$, $C_o = 1$ pF);

FIG. 20 is a graph for a comparison of RFID response receiver sensitivity frequency characteristics with respect to resistance by changing a short resistance R of a PIN diode (C-open = 1 pf, Low-f: $h = 0.014\lambda$, $w = 0.0525\lambda$, High-f: $h = 0.028\lambda$, $w = 0.035\lambda$);

FIG. 21 is a graph showing receiver gain for modulated waves from microstrip RFID (transmission/reception $\lambda/2$ dipole, distance $z = 5\lambda$);

FIG. 22 is a diagram showing three-dimensional location estimation based on a difference in reception phase of an RFID response signal by FMCW carrier transmission according to Example 3 of the present invention;

FIG. 23 is a graph showing a simulation estimating a three-dimensional location of an RFID according to Example 3 of the present invention (average in 100 rounds, RFID positional range 6 m × 6m × 6m, intervals between receiving antennas 50 cm);

FIG. 24 is a diagram showing an example of expanding a communication range (in-phase modulation) by forming an array of RFID microstrip elements according to Example 4 of the present invention;

FIG. 25 is a graph showing RFID response receiver sensitivity/directionality (transmission dipole distance 20λ, microstrip element: 0.364 × 0.0525λ)× three-element array according to Example 4 of the present invention;

FIG. 26 is a diagram showing an example of expanding a communication range (reversed-phase modulation) by forming an array of RFID microstrip elements according to Example 4 of the present invention;

FIG. 27 is a graph showing phase difference modulation of an RFID response receiver sensitivity directional 3-element array according to Example 4 of the present invention (transmission dipole distance 20λ, intervals between elements 0.7λ);

FIG. 28 is a graph showing phase difference modulation of an RFID response receiver sensitivity directional 3-element array according to Example 4 of the present invention (transmission dipole distance 20λ, intervals between elements 0.5λ);

FIG. 29 is an exemplary FORTRAN program for estimating the three-dimensional location of an RFID tag;

FIG. 30 is an exemplary FORTRAN program for estimating the three-dimensional location of an RFID tag;

FIG. 31 is an exemplary FORTRAN program for estimating the three-dimensional location of an RFID tag; and

FIG. 32 is an example of a FORTRAN program for estimating the three-dimensional location of an RFID tag.

EXPLANATIONS OF LETTERS OR NUMERALS

[0027]

c1201 In the case of single reading (packets cannot be multiplexed at the same time), semi-synchronous delay detection is performed.

c1202 In the case of double reading (two packets can be multiplexed at the same time), carrier phase split synchronous detection is performed.

c1203 A received carrier is modulated and ID codes are transmitted in packets.

c1204 tmn is determined for each RFID by generating random numbers

c1401, c2401, c2601 A receiver signal level of f_0+f_{L0} is read.

c2201 Synchronous detection of $\omega_n+\Delta$ is performed for each antenna reception signal.

c2202 A three-dimensional location is estimated based on at least three parameters; in practice, a reflected wave is present, and therefore time-delay measurements are performed using the MUSIC algorithm based on differences between multi-frequency response phases.

c2801 1 and 0 represent a phase difference of 180°.

c2802 High sensitivity is realized in a wide range

by successively switching between modulation phases.

c2803 Modulation phase of each element

D1, D2, D3, D4, D5, D6 Schottky-barrier diode

D7, D8 PIN diode

D9 Zener diode

BEST MODES FOR CARRYING OUT THE INVENTION

[0028] An embodiment of the present invention will now be described.

In the present invention, the dividing position of a divided microstrip antenna is slightly deviated from the longitudinal center point across strip conductors.

Now, assuming that the center point lies at the 50% position with respect to the length of the strip conductor, the dividing position is preferably 55% to 80%.

[0029] When the dividing position is 55%, the modulation efficiency (the level of a reply signal) is maximized. However, the resistive influence of a variable impedance element that is exerted on the receiving efficiency is increased.

Also, when the dividing position is 80%, the resistive influence of the variable impedance element that is exerted on the receiving efficiency is small, though the modulation efficiency is decreased.

[0030] Thus, it is preferred that, when the resistance of the variable impedance element is small, the dividing

position is approximately 55%, and when the resistance of the variable impedance element is relatively large, the dividing position is considerably further deviated from the center.

[0031] (Example 1)

FIG. 3 illustrates the basic configuration of an RFID tag device of the present invention. In this figure, the antenna of the RFID tag device includes a ground plane conductor, an insulating layer and a divided strip conductor. The RFID tag device shown in this figure is for use in the 2.45 GHz band, and all specified dimensions are in units of mm. Also, the dividing point of the divided strip conductor is deviated slightly more than equal division in the longitudinal direction, and this feature achieves the effect of maximizing the reception efficiency of the antenna.

[0032] FIG. 4 illustrates the details of the control circuit chip shown in FIG. 3 and connections between the divided strip conductor and the control circuit.

[0033] In FIG. 4, the control circuit chip and the antenna are connected at six points A, B, C, D, E and F. PIN diodes D7 and D8 for impedance modulation are connected between A and B and between D and E, respectively, and a feeding point of the antenna lies between C and F. Here, the point C is slightly deviated from the center point of the strip conductor width, and this feature achieves the effect of maximizing the

reception efficiency of the antenna. Also, the point F is connected to the ground plane conductor via a through-hole.

[0034] The operation principle of the power supply circuit in FIG. 4 is shown in FIG. 5. FIG. 5(a) is a boost rectifier circuit called "Cockcroft-Walton circuit", in which a plurality of rectifier diodes and capacitors are connected in a ladder configuration, so that a sine value signal with an amplitude of V_i can be output after being rectified to a DC voltage of $K(V_i-l_j)$ greater than V_i [K is the number of ladder steps; l_j is a forward drop voltage of a diode]. However, as shown in FIGS. 10 and 11, this circuit has a drawback in that when it is used in a high frequency band (e.g., 2.45 GHz), the junction capacitance of each diode becomes input load and therefore input impedance becomes extremely low, which lowers the output voltage.

[0035] FIG. 5(b) is an operational principle diagram of the boost rectifier circuit of the present invention. An $N\lambda g/4$ short stub (λg is an effective wavelength of the transmission path; N is an odd number being 1 or 3) exhibits an equivalent impedance of an inductance having a high Q-value in a high frequency range with respect to an input signal in the vicinity of λg. Even if a ladder boost section of FIG. 5(b) is a capacitive load, an inductive impedance can be maintained by a parallel resonance operation. On the other hand, in a tank

circuit boost section of FIG. 5(b), the inductive impedance and a capacitive feed impedance generate an RF signal, which has a large amplitude of $V_L = V_i / (R_L \cdot wc) >> V_i$, between G and F by a series resonance operation, so that the circuit of FIG. 5(b) can obtain a DC output voltage of $20V_i$ or more.

[0036] FIG. 17 is a behavioral analysis result of the boost rectifier circuit of the present invention, from which it is appreciated how an input voltage of 50 Ω / -10 dBm (0.07 V) is boosted and rectified to 1 V or more at 2.45 GHz.

[0037] Next, the control circuit chip of FIG. 4 is described in detail.

[0038] When V_{DD} is applied, an oscillator circuit generates a clock signal of f_s. When V_{DD} and the clock signal are applied, an output timing circuit generates a timing signal (an output enable signal) for anticollision as shown in FIGS. 12 and 13. When the output enable signal and the clock signal are applied, an address counter outputs memory read addresses one after another for each clock "L" pulse. Note that the data transmission rate in this case is $2f_s / L$ (bit/sec). The memory sequentially outputs 2-bit information recorded at addresses designated by the address counter. A 1/4 frequency divider outputs a signal corresponding to 1/4 of f_s. A shift register operates in accordance with the clock f_s, and phase-shifts the output of the

1/4 frequency divider in units of 90°. When the output enable signal is applied, a data selector selects and outputs one of four phase outputs (0° to 270°) of the shift register in accordance with a 2-bit memory output.

[0039] However, it is possible to apply MPSK modulation by using a 1/M frequency divider, an M-stage shift register and an M-input data selector. In this case, it is possible to achieve the effect of increasing the amount of information that is transmitted per unit transmission power.

[0040] The output of the data selector changes the amplitude of current flowing through resistances to the PIN diodes D7 and D8 with a cycle of f_s / 4, thereby modulating a connection impedance between the divided strip conductors. As shown in FIG. 14, the change of the impedance changes a mutual coupling impedance between an antenna of an interrogator and the antenna of the RFID tag, so that a reflection coefficient Γ of the antenna of the interrogator is changed with a cycle of f_s / 4. FIG. 15 is an example of a signal measured with a spectrum analyzer. That is, from which it is possible to identify signal components ($f_O + f_{LO}$, $f_O + 3f_{LO}$, etc.), which are generated as a result of an incident wave of f_O having been modulated by the change of Γ with a cycle of f_{LO}. In this case, $f_{LO} = f_s / 4$, and because the interrogator can accurately determine f_O, it is possible to readily evaluate the oscillating frequency f_s of the

oscillator circuit at the tag based on the measured spectrum ($f_O + f_{LO}$, $f_O + 3f_{LO}$, etc.). Specifically, by using, for example, a quartz resonator temperature sensor as the oscillator circuit at the tag, it is also possible for the interrogator to monitor the ambient temperature at the tag.

[0041] Incidentally, the microstrip antenna used for the RFID tag device of the present invention is explained with respect to its property. The microstrip antenna is configured simply by providing a ground plane close to a plate-like dipole antenna, and therefore might be considered as if it is an antenna that behaves as a dipole, but in fact, its behavioral principle is considerably different from that of the dipole antenna. Specifically, the dipole antenna is an electric current antenna, and the strip antenna is a magnetic current antenna. The reason why in the present invention, two PIN diodes for impedance modulation are provided at opposite ends of the microstrip conductor in the width direction is that electric current flowing through the strip conductors is concentrated at the opposite ends in the width direction.

[0042] FIG. 16 is an example of analyzing the level of a response signal that can be received by an interrogator by using antenna length L as a parameter in the evaluation system of FIG. 14, with respect to the case where a conventional dipole antenna having no ground

plate is used in an RFID tag and the case where the divided microstrip antenna of the present invention is used in an RFID tag. As can be seen from this figure, the method of the present invention is capable of receiving the response signal with a level greater by about 10 dB (10 times greater power) compared to the conventional method.

[0043] FIGS. 18 through 20 show changes in frequency at response receiver levels in the evaluation system of FIG. 14 with respect to design parameters w and h of the microstrip antenna (it is assumed that L = 0.36 λ is fixed). It can be appreciated from FIG. 18 that by reducing h (the thickness of an insulator), it is possible to make adaptation to lower frequencies with the same size (size reduction with the same frequency), but an available frequency bandwidth becomes narrow.

[0044] Also, it can be appreciated from FIG. 19 that by increasing w (the strip conductor width), it is possible to make adaptation to lower frequencies with the same size, but an available frequency bandwidth becomes narrow.

[0045] FIG. 20 is a result of analyzing influences of a series resistance in PIN diodes for impedance modulation that are exerted on the receiver level with respect to the cases of making adaptation to lower and higher frequencies with the same size. As can be seen from this figure, in the case of size reduction with the same

frequency (reduction in h, increase in w), considerable influences are exerted by the series resistance of the PIN diodes, and therefore it is necessary to reduce the resistance in order to obtain a high response receiver level. In order to allow the PIN diodes to operate with low resistance, there is no choice but to apply a large current or increase junction capacitance (large area, short junction). The large current increases power consumption of the RFID tag device, and therefore is undesirable.

[0046] FIG. 21 is a result of analyzing a maximum response receiver level in the evaluation system of FIG. 14 by using the series resistance and junction capacitance of the PIN diodes as parameters. As can be seen from this figure, the response receiver level does not change substantially when the junction capacitance of the PIN diodes is increased, and therefore it is possible to obtain a high response receiver level even by using relatively low-cost PIN diodes.

[0047] Also, instead of the PIN diodes, it is possible to use varactor diodes, and transistors such as MOSFET may also be used. In such a case, it is possible to further reduce the power consumption.

[0048] Also, when considering longitudinal connections of capacitors in a ladder boost rectifier circuit of a power receiving circuit as GND- and receiving-side rails, it is possible to consider diodes as rungs that join

them. Capacitances of all the capacitors are normally equalized to maximize the booster efficiency, but in the present invention, the capacitor capacitance of the receiving-side rail is made smaller by one digit compared to that of the GND-side rail (specifically, GND-side rail: receiving-side rail = 1 : 0.05), and the first diode (between the GND and the receiving point) is eliminated, whereby it is possible to reduce input load capacity and receive a high-frequency and high-impedance input with a DC short.

[0049] (Example 2)

(A method for detecting the position of a moving object without an RFID tag)

The feature of the RFID tag of the present invention that is capable of relatively long range communication in spite of having no power supply is utilized.

[0050] Assuming that the positions of tags #1 through #4 and interrogators #1 and #2 are known as shown in FIG. 6, it is possible to estimate the position of a mobile object based on information concerning paths obstructed by the moving object.

[0051] In this case, a system may be configured such that $f_{m1} = f_{m2}$, $f_{s1} = f_{s2} = f_{s3} = f_{s4}$, the interrogators provide CW outputs in a time-division system, and the tags respond by an anticollision method.

[0052] Further, a system may be configured such that $f_{m1} \neq f_{m2}$, $f_{s1} = f_{s2} = f_{s3} = f_{s4}$, the interrogators

successively provide CW outputs, and the tags respond by an anticollision method.

[0053] Furthermore, a system may be configured such that $f_{m1} \neq f_{m2}$, f_{s1}, f_{s2}, f_{s3} and f_{s4} are all different frequencies, and the interrogators successively provide CW outputs.

[0054] (Example 3)

(A method for detecting the position of a moving object with RFID)

The feature of the RFID tag of the present invention that is capable of relatively long range communication in spite of having no power supply is utilized.

[0055] As shown in FIGS. 22 and 23, a plurality of receiving antennas are used at the master device, and CW signals are transmitted at two or more frequencies to detect differences in phase between response signals from RFID tags, making it possible to estimate three-dimensional locations of the RFID tags.

[0056] FIG. 7 illustrates the configuration of a master device. A Fourier transform section performs time-series Fourier integration on Re and Im data of antennas #1 through #4 to calculate a spectrum phase at a frequency Δ. In this case, it is assumed that phase differences due to each antenna cable and down converter and a time delay in operations of a selecting switch are calibrated for the compensation.

[0057] Note that FIGS. 29 to 31 present an example of an

algorithm implemented in FORTRAN language for estimating three-dimensional locations of RFID tags in the configuration of FIG. 7, and FIG. 30 is an example of the program. Also, the analysis of RMS error in estimation of three-dimensional locations of the RFID tags in FIG. 23 is a result of computer simulation by the program of FIGS. 29 to 31 using the number of receiving antennas and error in distance measurement as parameters.

Note that in the program shown in FIGS. 29 to 31, the simulation for estimating the three-dimensional locations of the RFID tags is carried out in the following procedure.

(1) Assuming that radio wave frequencies output from interrogators are f_1 = 2.000 GHZ, f_2 = 2.025 GHZ and $f_0 = 2(f_2-f_1)$ = 0.05 GHZ and λ_0 = 15 cm, the delay evaluation cycle length is taken as dlh = λ_0 / f_0 (cm) and the number of receiving antennas is taken as na = 16.

(2) The three-dimensional locations of the RFID tags are entered.

(3) Distances D are obtained based on phases at which response signals from the RFIDs are received by receiving antennas. In this case, spacing between the receiving antennas are taken as 50 cm.

$$D = \{\text{Phase }(f_2) - \text{Phase }(f_1)\} \times 3 \times 10^{10} / \pi f_0 \text{ (cm)}$$

(4) Noise is added to the distances D obtained based on the phases of reception by the receiving antennas,

and differences in distance to a reference antenna are calculated. Here, in common with all the distances D obtained at the above step (3), offsets such as distances D_X from transmitting antennas of interrogators to the RFID tags and differences in response phase of the RFID tags are included, and therefore the reason why the differences to the reference antenna are calculated is to achieve the effect of eliminating influences of D_x and so on.

(5) The differences in distance between the receiving antennas are compensated for the delay evaluation cycle length dlh.

(6) Three-dimensional locations X_P, Y_P, Z_P of the RFID tags are assumed.

(7) Distances to the assumed tag locations X_P, Y_P, Z_P are obtained based on the phases of reception by the receiving antennas.

(8) The differences in distance between the antennas, which are actually received at the above step (5), are compared with differences between the distances to the assumed tag locations that are obtained at the above step (7) based on the phases of reception by the receiving antennas.

(9) The distance differences compared above are compensated for the delay evaluation cycle length dlh.

(10) Error energies are obtained with respect to the compared distance differences between the receiving

antennas that have been subjected to the above cycle compensation.

(11) After repeating the processes of the above steps (6) through (10), three-dimensional locations of five positions of the tag are listed in ascending order of error energy.

(12) Approximate results for estimating the three-dimensional locations of the listed five positions of the tag and the error RMS values are displayed.

(13) An assumed tag location that provides a minimum error energy is obtained in three dimensions by repeating the above processes in (6) through (10) with more fragmented steps focusing on each of the three-dimensional locations of the listed five positions of the tag.

(14) The three-dimensional assumed tag location that provides the minimum error energy is displayed as a finally estimated RFID tag location.

[0058] (Example 4)

(A method for longer-range communication with RFID tags)

The RFID tag of the present invention, even by itself, can perform communication within a relatively long range of about 10 m. However, if it is used for a sign on an expressway and so on, the communication range of about 10 m is highly unlikely to be sufficient. Accordingly, RFID tags of the present invention are arranged in an

array to add a phase difference to a response signal from each tag, so that the response signal can be returned with high sensitivity to interrogators in a wide area, thereby making it possible to perform communication within a range of about 100 m. An example thereof is shown in FIGS. 24 through 28.

[0059] The method described herein controls directionality by the arrangement of the RFID tags and combinations of response signal phases at 0°/180° for each tag, however, it is also possible to more strictly control the directionality by assigning more fragmented phase differences as shown in FIG. 8.

[0060] Note that the combinations of phases at 0°/180° in FIG. 24 through 28 can be readily realized by using an E_XOR as shown in FIG. 9.

Also, it is made possible to communicate with interrogators in a wide area by periodically changing the combinations of phases provided herein to perform scanning with a beam of intense response radio waves that can be returned only within a narrow area.

INDUSTRIAL APPLICABILITY

[0061] Common features of being inexpensive, having no power supply, requiring no maintenance and being capable of long range communication (up to about 100 m) are used as the means of implementation.

[0062] (1) Because of the ease of attachment to a road

sign, etc., and the fact that information can be read by an interrogator from relatively afar and, if radio wave diffraction is utilized, even from a position behind another vehicle, it is possible to construct an intelligent navigation system notifying information concerning the speed limit, indication of a curve/fork, etc., to the driver and an automatic operation or safety support device of the vehicle.

[0063] (2) Because of the ease of attachment to an advertisement material such as a poster and the fact that information can be read by an interrogator from relatively afar, it is possible to realize an applied device for reading an Internet home page address on a posted advertisement from a distance and construct a product advertising system. In this case, it is conceivable to simultaneously read a plurality of posters having the same address or simultaneously read a plurality of posters having a different address. A reader (an interrogator) owned by the user incorporates, as a part of ID, a code that represents a color corresponding to visual information of a poster or attached tag or a relatively simple symbol/mark to facilitate selection of an Internet link, avoid displaying identical addresses and present displays in order of address hierarchy.

[0064] (3) Because of the ease of attachment to a sample or product such as an exhibit and the fact that

information can be read from relatively afar, it is possible to construct a reservation and market research system that, without necessitating approaching the exhibit, transmits a product reservation and information added with preferences regarding the size and color to the seller of the product (a reader is additionally provided with a wireless LAN function or a cell phone function, or the reader accumulates information and returns it to the seller). In this case, it is conceivable to simultaneously read information concerning a plurality of products having the same ID from a display shelf or a showcase or simultaneously read a plurality of pieces of information concerning products having a different ID. The reader owned by the user incorporates, as a part of ID, a code that represents a color corresponding to visual information of a product or attached tag or a relatively simple symbol/mark to facilitate selection of a preferred product, avoid displaying identical ID codes or symbols and provide displays in order of ID code hierarchy.

[0065] (4) Because of easy incorporation into cars, home appliances, etc., and the feasibility of being read from relatively afar, it is possible to construct a system for performing classification for recycling or deterring illegal waste dumping, stealing for resale, etc. Specifically, by recording, together with an ID code, not only information at the time of production but also

information concerning the owner or information concerning the presence or absence of hazardous substances, it is made possible to allow a relatively simple reader to perform concurrent identification from afar.

[0066] (5) According to the RFID tag device of the present invention, not only information recorded in a memory but also information regarding a selected voting switch or the like can be returned as a response signal and readily read from relatively afar, and therefore it is possible to construct an instant voting/ballot counting system at an event site or the like. The RFID tag of the present invention has no power supply and a thin and relatively simple structure, and therefore the cost for mass production is conceivably about several tens of yen. Accordingly, it can be left uncollected after used as an invitation or ticket for an event, or it can be collected and repeatedly used.

[0067] (6) According to the RFID tag of the present invention, not only information recorded in a memory but also information measured by various transducers can be returned as a response signal and read from relatively afar, and therefore it is possible to construct a system that uses a relatively small number of interrogators to continuously monitor physical condition information such as an ill-conditioned person's heartbeat from afar without imposing a burden on that person.

[0068] (7) According to the RFID tag of the present invention, not only information recorded in a memory but also information measured by various transducers can be returned as a response signal and read from relatively afar, and therefore it is possible to construct a system that continuously monitors a device, such as high-voltage power transmission and distribution equipment, which is difficult to connect to a sensor and cannot be readily suspended for maintenance because it is dangerous to gain access thereto.

[0069] (8) In the example of FIG. 4, the stub resonance boost rectifier circuit and the control circuit in FIG. 2 illustrating the configuration of the RFID tag device of the present invention are integrated as a control circuit chip. However, a highly-versatile, low power consumption microprocessor (e.g., PIC16F684 manufactured by Microchip Technology Inc.) can be used as the control circuit and combined with the stub resonance boost rectifier circuit. By configuring as such, it is made possible to input analog data or digital data, so that such data can be temporarily stored in the RFID tag or can be stored in an EEPROM for a long period of time. Further, it can be used for remote control reception with a home appliance or the like, but also it is possible to read a variety of types of information with no power being supplied. For example, with a reader (a remote controller), it is possible to check information

such as:

- Power is not being supplied;
- xxx is out of order;
- yyy is still inside xxx;
- yyy is reserved for xxx;
- yyy was last used on x month, x day at x o'clock, x minutes.

[0070] (9) The RFID tag device of the present invention can be operated to the same standard as a 2.45 GHz wireless LAN, and therefore it is possible to use, as an interrogator, a wireless LAN base station or a wireless LAN terminal. In this case, a 2.45 GHz carrier signal needs to be transmitted from the wireless LAN to provide operating power for the RFID tag device, but it may be a radio wave of an FHSS or OFDM scheme, which is a wireless LAN standard. The RFID tag device returns reply information on a subcarrier signal offset by an oscillating frequency of a local transmitter in the tag, and therefore the reply information from the RFID tag can be read at the wireless LAN by demodulating a subcarrier signal synchronously detected with a transmission carrier.